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<b>(54) Title:</b> SURFACE MOUNT CONDUCTIVE POLYMER DEVICES AND METHOD FOR MANUFACTURING SUCH DEVICES  <b>(57) Abstract</b>  <p>A conductive polymer device includes an active element comprising a conductive polymeric layer laminated between a pair of electrodes to which terminal leads are attached. The active element is enclosed in an insulative package. Each of the electrodes may be formed integrally with its associated terminal lead in a single lead frame, with a layer of conductive polymeric material laminated between two such lead frames. Alternatively, a conductive polymeric layer may be laminated between two electrodes, with a terminal lead then being soldered to each electrode. The insulative package for the active element may be either an over-molded housing encasing the active element, or a pre-molded housing having a cavity into which the active element is installed, and which is then hermetically sealed with a suitable sealant material.</p>		

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1 SURFACE MOUNT CONDUCTIVE  
2 POLYMER DEVICES AND METHOD  
3 FOR MANUFACTURING SUCH DEVICES  
4

5 Background of the Invention  
6

7 The present invention relates broadly to the field of  
8 conductive polymer devices, including methods for manufacturing  
9 such devices. More specifically, it relates to electronic devices  
10 comprising a conductive polymer layer laminated between a pair of  
11 conductive electrodes and packaged in an insulative housing, and  
12 to the method for manufacturing such devices.

13 Electronic devices that include an element made from a  
14 conductive polymer have become increasingly popular, being used  
15 in a variety of applications. They have achieved widespread usage,  
16 for example, in overcurrent protection and self-regulating heater  
17 applications, in which a polymeric material having a positive  
18 temperature coefficient of resistance is employed. Examples of  
19 positive temperature coefficient (PTC) polymeric materials, and of  
20 devices incorporating such materials, are disclosed in the following  
21 U.S. patents:

22 3,823,217 - Kampe  
23 4,237,441 - van Konynenburg  
24 4,238,812 - Middleman et al.  
25 4,317,027 - Middleman et al.  
26 4,329,726 - Middleman et al.  
27 4,413,301 - Middleman et al.  
28 4,426,633 - Taylor  
29 4,445,026 - Walker  
30 4,481,498 - McTavish et al.

1	4,545,926 - Fouts, Jr. et al.
2	4,639,818 - Cherian
3	4,647,894 - Ratell
4	4,647,896 - Ratell
5	4,685,025 - Carlomagno
6	4,774,024 - Deep et al.
7	4,689,475 - Kleiner et al.
8	4,732,701 - Nishii et al.
9	4,769,901 - Nagahori
10	4,787,135 - Nagahori
11	4,800,253 - Kleiner et al.
12	4,849,133 - Yoshida et al.
13	4,876,439 - Nagahori
14	4,884,163 - Deep et al.
15	4,907,340 - Fang et al.
16	4,951,382 - Jacobs et al.
17	4,951,384 - Jacobs et al.
18	4,955,267 - Jacobs et al.
19	4,980,541 - Shafe et al.
20	5,049,850 - Evans
21	5,140,297 - Jacobs et al.
22	5,171,774 - Ueno et al.
23	5,174,924 - Yamada et al.
24	5,178,797 - Evans
25	5,181,006 - Shafe et al.
26	5,190,697 - Ohkita et al.
27	5,195,013 - Jacobs et al.
28	5,227,946 - Jacobs et al.
29	5,241,741 - Sugaya

1 5,250,228 - Baigrie et al.

2 5,280,263 - Sugaya

3 5,358,793 - Hanada et al.

4 The conductive polymer devices of the prior art are typically  
5 made in a batch process, in which a sheet of conductive polymer  
6 material is formed, and then laminated between sheets of  
7 conductive metal foil. The laminated assembly is then cut into  
8 individual electronic components. More specifically, the polymeric  
9 sheet is formed by batch mixing or compounding a polymer (e.g.,  
10 high density polyethylene, or HDPE), a conductive filler such as  
11 carbon black or various metallic fillers, and other materials (e.g.,  
12 other fillers and antioxidants), then forming a sheet of conductive  
13 polymer material, using either single screw extrusion or  
14 compression/injection molding.

15 Furthermore (as disclosed, for example, in U.S. Patent No.  
16 4,426,633 - Taylor), the materials may be mixed, and, while heated,  
17 extruded through a pelletizing die and chopped to form pellets.  
18 The pellets are then vacuum-dried and extruded into a tape or  
19 sheet that is cut into pieces, each of which is laminated between a  
20 pair of foil sheets using a discrete, high temperature compression  
21 process, before finally being cut into the individual components.

22 It is of great importance, particularly in overcurrent  
23 protection applications, for the material to have a high degree of  
24 uniformity in such areas as volume resistivity, filler dispersion,  
25 process heat history, and degree of polymer cross-linking, in  
26 devices having the same nominal electrical performance  
27 specifications. A drawback to the batch processing of the prior art  
28 is that a relatively high degree of variability is introduced into the  
29 manufactured devices. This drawback stems from several sources.

1           First, there is the inherent variability in the batch mixing or  
2           compounding step of the process. Specifically, there is an inherent  
3           variability, on a batch-to batch basis, of material mix, set-up  
4           conditions, and process conditions. Furthermore, there is often an  
5           insufficient mixing of the materials, and the batch mixing process  
6           requires a secondary melt processing (such as single screw  
7           extrusion) to form the material into a usable shape. Some  
8           compensation for the batch-to-batch variability may be obtained by  
9           mixing together multiple master batches prior to the secondary  
10          melt processing, but the result is still a degree of variability in  
11          resistance in the final sheet, introduced by the typical use of a  
12          single screw extruder in the secondary melt processing. This  
13          variability, which may include non-normal distributions exhibiting  
14          multi-modal resistance peaks, is typically caused by non-uniform  
15          mixing of the master batches and the introduction of additional  
16          heat history to the material during the secondary melt process in  
17          the extruder. The resulting degree of variability may be  
18          unacceptable for many applications.

19          In addition, the batch mixing step produces compounded  
20          pellets that need to be stored in an environment in which  
21          temperature, humidity, and dust content are tightly controlled, to  
22          minimize the presence of impurities and moisture that need to be  
23          removed to avoid bubbles in the foil-polymer interface of the  
24          laminated final product.

25          Variations in both physical dimensions and resistance  
26          characteristics are also introduced in the batch lamination step of  
27          the manufacturing process, as a result of different temperatures,  
28          pressures, and gap spacings among the multiple lamination  
29          machines, as well as stroke-to-stroke variations on any given single

1 machine.

2 Furthermore, each of the above-described discrete processes  
3 contributes an additional and different heat history to the product,  
4 degrading the base polymeric resin due to thermal oxidation from  
5 exposure to temperatures above the melting point of the polymer.  
6 This can result in excessive variances in the electrical performance  
7 characteristics of the finished product.

8 The products made by the above-described processes, i.e.,  
9 polymer PTC devices, are typically mounted on a circuit board for  
10 use in an electronic circuit. A particularly popular and  
11 advantageous packaging configuration for many types of  
12 board-mounted devices and components is that which is known as  
13 "surface mounting technology", or "SMT". SMT components are  
14 characterized by "J"-shaped or "gull wing" terminal leads, and by an  
15 outer casing configuration that facilitates automated component  
16 handling (e.g., vacuum-type "pick-and-place" robots and optical  
17 character recognition for component positioning and orientation).  
18 A significant advantage of SMT-type devices over so-called  
19 "through-hole" devices is that the former can readily be mounted  
20 on both side of a printed circuit board, while the latter cannot.

21 SMT-type polymer PTC components have been developed in  
22 the prior art, as shown, for example, in U. S. patent No. 5,241,741  
23 - Sugaya. These prior art SMT-type polymer PTC devices  
24 comprise a layer of conductive polymeric material sandwiched  
25 between a pair of metal foil electrodes, with a terminal lead  
26 spot-welded or soldered to each electrode. Such devices have a  
27 number of drawbacks. For example, they do not readily lend  
28 themselves to state-of-the art automated manufacturing techniques,  
29 such as continuous processing, thereby increasing manufacturing

1 costs. In many cases, the packaging design of the prior art devices  
2 is not suitable for several of the SMT component handling  
3 techniques, such as those mentioned above. Furthermore, the  
4 prior art devices with soldered terminal leads cannot be wave  
5 soldered to the underside of printed circuit boards, because the  
6 wave soldering process may loosen the terminal lead/electrode  
7 solder joint, resulting in a shifting of the terminal leads relative to  
8 the electrodes. To allow wave soldering, some prior art devices  
9 employ leads that are spot-welded to the electrodes, but this  
10 process is expensive, difficult to control, and conducive to creating  
11 localized areas of high resistance in the polymeric layer, which, in  
12 turn, cause performance degrading "hot spots" when the device is  
13 actuated or "tripped".

14 Nor can these prior art devices be easily glued to the  
15 underside of the board, since they typically lack insulative packages  
16 that can be adhesively attached to the board. Without underboard  
17 placement, these devices lose a significant advantage of SMT  
18 devices. For similar reasons, many prior art SMT-type polymer  
19 PCT devices either cannot be reflow soldered, or they can be  
20 reflow soldered only under carefully controlled conditions.  
21 Moreover, the prior art SMT-type polymer PTC devices have  
22 exposed electrodes and no insulative packaging to protect against  
23 short circuits or physical damage.

24 There has thus been a long-felt, but as yet unmet need for a  
25 process for manufacturing conductive polymer devices, particularly  
26 polymer PTC devices, that avoids the above-described  
27 disadvantages of the prior art batch process methods, while  
28 maintaining good uniformity of physical and electrical  
29 characteristics among devices with the same nominal specifications,



1 and while keeping per unit manufacturing costs acceptably low.

2 There has also been a need for SMT-type conductive  
3 polymer devices, particularly polymer PTC devices, that can be  
4 readily manufactured using a continuous process, and that are easily  
5 adaptable to state-of-the-art component handling equipment and  
6 methods. There is a still further need for devices of this nature  
7 that can also be soldered to the underside of a printed circuit  
8 board using conventional wave soldering techniques, and that can  
9 be reflow soldered with fewer limitations on the conditions  
10 imposed. Furthermore, it would be advantageous to provide  
11 devices that exhibit the aforementioned properties, while also being  
12 packaged so as to be protected against short circuits and physical  
13 shock.

14 Summary of the Invention

15 Broadly, the present invention is a polymer PTC device,  
16 wherein a conductive polymeric layer is laminated between a pair  
17 of electrodes to which terminal leads are attached, and the  
18 laminated active element assembly is enclosed in a fluid-tight,  
19 insulative SMT-type package. Each of the electrodes may be  
20 formed integrally with its associated terminal lead in a single lead  
21 frame, with a layer of conductive polymer material laminated  
22 between two such lead frames. Alternatively, a conductive  
23 polymeric layer may be laminated between two electrodes, with a  
24 terminal lead then being soldered to each electrode. The  
25 insulative package for either of these active element assemblies  
26 may be either an over-molded housing encasing the laminated  
27 assembly, or a pre-molded housing, into which the laminated  
28 assembly is installed and hermetically sealed.

29 The active element assembly of the polymer PTC device of

1 the present invention is preferably manufactured by a continuous  
2 process known as "direct extrusion". In direct extrusion, the steps  
3 of compounding the materials of the conductive polymer mixture,  
4 extruding the polymeric mixture, and laminating the extruded  
5 material are performed serially in a continuous process, with  
6 closed-loop process control by a microprocessor. A specific  
7 embodiment of this method employs a twin screw compounding  
8 extruder that compounds the polymeric mixture from materials  
9 received, in predetermined proportions, from gravimetric feeders,  
10 then extrudes a compounded conductive polymeric material in the  
11 melt phase. The extrudate is then fed into a gear pump that  
12 allows the extruder to discharge the compounded material, while it  
13 is still in the melt stage, at a relatively low pressure, thereby  
14 minimizing or avoiding the introduction of unnecessary shear  
15 forces and work into the material. The gear pump then produces a  
16 substantially constant volumetric output of the compounded "melt  
17 phase" material at sufficiently high  
18 pressure for delivery into a sheet die. The sheet die forms the  
19 compounded material, while still in the melt phase, into a high  
20 tolerance continuous web. The formed polymeric web, while at a  
21 temperature just below the melt temperature of the polymeric  
22 material, is fed into a mechanism that laminates a continuous web  
23 of conductive metal foil onto each side of the polymeric web, the  
24 foil webs being pre-heated to a temperature slightly above the melt  
25 temperature of the polymeric material. The continuous web of  
26 laminate may then be cut into measured lengths, prior to forming  
27 individual active elements. Alternatively, the laminated web may  
28 be wound into a roll prior to forming the individual active  
29 elements.

1           In the embodiments in which the electrodes are formed  
2           integrally with the terminal leads, each of the foil webs is in the  
3           form of a lead frame blank, wherein the foil web is provided with  
4           registration holes along each edge. After lamination, the  
5           laminated webs are cut and trimmed to form individual active  
6           element assemblies, each of which is attached to the lead frame by  
7           lead elements. While still attached to the lead frame, the  
8           individual active element assemblies may then be encapsulated in a  
9           conformal over-molded housing, or they may be placed in a  
10          pre-molded molded housing that is then hermetically sealed with a  
11          suitable potting material. Finally, the leads are separated from the  
12          lead frame and formed into a terminal lead shape that is suitable  
13          for an SMT-type device.

14          In the embodiments in which the terminal leads are  
15          separately attached to the electrodes, the laminated webs are cut  
16          into strips of suitable length. A first terminal lead frame carrying a  
17          first plurality of terminal leads is soldered to one side of the  
18          laminated strip, and a second terminal lead frame carrying a  
19          second plurality of terminal leads is soldered to the opposite side  
20          of the strip. The strip is then cut and trimmed to form individual  
21          active elements, each connected to the two lead frames. While still  
22          so connected, the active elements may be either encapsulated in a  
23          conformal over-molded housing or sealed into a pre-molded  
24          housing, as with the integral electrode/lead embodiments. Finally,  
25          the terminal leads are separated from the lead frame and formed  
26          into the desired shape.

27          In all embodiments, the housing provides protection from  
28          hostile chemical and physical environments, such as those  
29          encountered during wave soldering. Specifically, the housing

1 provides protection of the active element and the lead/electrode  
2 connection from physical shock, while both isolating these  
3 components from the environment and electrically insulating these  
4 components to minimize the occurrence of short circuits.

5 Furthermore, the housing, being typically formed from a moldable  
6 thermoplastic material, is adhesively attachable to the material  
7 from which circuit boards are made, thus allowing the devices to  
8 be glued to the underside of the board. Moreover, the housing  
9 dissipates sufficient heat to allow the device to be attached to a  
10 circuit board by reflow or wave soldering, without substantial risk  
11 of damage to its internal components, and without adding heat  
12 histories to the polymeric element that can affect its stability of  
13 resistance. In addition, the heat dissipation provided by the  
14 housing allows the terminal leads to be soldered to the electrodes  
15 without significant risk of having the lead/electrode joint degraded  
16 or shifted when the device is soldered to the circuit board.

17 The continuous manufacturing process produces articles of  
18 manufacture, each comprising a formed polymeric layer  
19 sandwiched between metallic foil electrodes, suitable for  
20 fabrication into polymer PTC devices, that have undergone  
21 minimum heat history, and that have avoided the batch-to-batch  
22 variability in material thickness and resistivity inherent in the  
23 above-mentioned prior art batch processes. Furthermore, the  
24 polymer PTC devices manufactured from components produced by  
25 this method exhibit superior aging characteristics and voltage  
26 stability as compared with products made by the prior art  
27 processes.

28 In addition, the present invention provides SMT-type  
29 polymer PTC devices that exhibit the benefits and advantages of

1 the SMT configuration, and that can be readily wave soldered or  
2 reflow soldered to circuit boards, and/or adhesively attached to  
3 circuit boards, without significant risk of damage or degradation in  
4 performance, thereby allowing these devices to be mounted on  
5 both sides of a circuit board. Furthermore, the devices constructed  
6 in accordance with the present invention can employ soldered  
7 connections between the leads and the electrodes, and yet still be  
8 reflow soldered or wave soldered. Moreover, the devices  
9 constructed in accordance with the present invention are provided  
10 with physical protection, electrical insulation, and environmental  
11 isolation. In addition, the devices constructed in accordance with  
12 the present invention are adapted for mass production in  
13 accordance with the continuous process disclosed herein.

14 These and other advantages of the invention will be more  
15 fully appreciated from the detailed description that follows.

16 Brief Description of the Drawings

17 Figure 1 is a semi-schematic, side elevational view of the  
18 apparatus used to carry out a continuous process for manufacturing  
19 a conductive polymer device, in accordance with a preferred  
20 embodiment of the present invention;

21 Figure 2 is a detailed view of the laminated polymeric  
22 material produced by the apparatus of Figure 1, as encompassed  
23 within the broken outline 2 in Figure 1;

24 Figure 3 is a top plan view of the apparatus of Figure 1,  
25 taken along line 3 - 3 of Figure 1;

26 Figure 4 is a cross-sectional view of a conductive polymer  
27 device constructed in accordance with the method of the present  
28 invention;

29 Figure 5 is a schematic diagram of the control system used

1 in the present invention;

2 Figure 6A is fragmentary perspective view of a laminated  
3 web comprising a pair of conductive metal lead frames with a  
4 conductive polymer web laminated between them, as employed in  
5 manufacturing laminated conductive polymer active elements in  
6 accordance with first and second preferred embodiments of the  
7 present invention;

8 Figure 6B is a fragmentary perspective view, similar to that  
9 of Figure 6A, showing the laminated web after it has been trimmed  
10 and cut to form a plurality of individual laminated conductive  
11 polymer active elements in accordance with the first and second  
12 preferred embodiments of the present invention;

13 Figure 7 is a perspective view of a laminated conductive  
14 polymer active element, as employed in the first and second  
15 preferred embodiments of the present invention, prior to its being  
16 packaged in a housing;

17 Figure 8 is a cross-sectional view taken along line 8 - 8 of  
18 Figure 7;

19 Figure 9 is a cross-sectional view, similar to that of Figure 8,  
20 showing the laminated active element of Figure 7 encapsulated in a  
21 conforming over-molded housing, in accordance with the first  
22 preferred embodiment of the invention;

23 Figure 10 is an end elevational view of the device of Figure  
24 9, showing the terminal leads formed into an SMT configuration;

25 Figure 11 is a perspective view of the device of Figure 10;

26 Figure 12 is a perspective view showing the laminated active  
27 element of Figure 7 installed in a pre-molded housing, in  
28 accordance with the second preferred embodiment of the  
29 invention, prior to hermetic sealing;

1           Figure 13 is a cross-sectional view taken along line 13 - 13 of  
2           Figure 12, but after the housing is  
3           hermetically sealed;

4           Figure 14A is a perspective view of a strip of the laminated  
5           web from which the active elements of the present invention are  
6           made, showing the strip attached to a lead frame as a step in the  
7           construction of third and fourth preferred embodiments of the  
8           present invention;

9           Figure 14B is a perspective view of a laminated polymer  
10          PTC active element, as employed in the third and fourth preferred  
11          embodiments of the present invention, showing the active element  
12          attached to a lead frame;

13          Figure 15 is a cross-sectional view taken along line 15 - 15 of  
14          Figure 14B, but showing the laminated active element encapsulated  
15          in a conformal over-molded housing, in accordance with the third  
16          preferred embodiment of the invention;

17          Figure 16 is a perspective view of the laminated active  
18          element of Figure 14 installed in a pre-molded housing, in  
19          accordance with the fourth preferred embodiment of the invention,  
20          prior to hermetic sealing; and

21          Figure 17 is a cross-sectional view taken along line 17 - 17 of  
22          Figure 16, but after the housing is hermetically sealed.

23                           Detailed Description of Invention

24          A.    **Continuous Process for Manufacturing the Active Element**

25               Referring now to the drawings, a continuous process for the  
26               manufacturing of the active element of conductive polymer PTC  
27               devices, in accordance with the preferred embodiments of the  
28               invention, will be described in conjunction with a description of the  
29               apparatus used to carry out the process.

1           The process begins with a compounding apparatus,  
2           comprising, in the preferred embodiment, a twin screw  
3           compounding extruder 10, such as the type available from  
4           American Leistritz Extruder Corporation, of Somerville, NJ, under  
5           the model designation "ZSE-27". The twin screw compounding  
6           extruder 10 includes dual extruder screws (not shown), selectively  
7           rotatable in co-rotation and counterrotation modes.

8           The materials from which the polymer PTC active element is  
9           compounded are fed into the compounding extruder 10, in  
10          predetermined proportions, and at predetermined feed rates, from  
11          a first gravimetric feeder 12 and a second gravimetric feeder 14,  
12          which may be of either the single screw or the twin screw type  
13          (dependent on the materials employed), both types being  
14          conventional, commercially-available devices. In a preferred  
15          embodiment of the invention, a suitable polymer, such as high  
16          density polyethylene (HDPE) or polyvinylidene difluoride (PVDF),  
17          is fed, in commercially-available pelletized or powdered form, into  
18          the first (preferably single screw) feeder 12, while carbon black is  
19          fed into the second (preferably twin screw) feeder 14. The  
20          particular types of the constituent materials, and their proportions,  
21          depend upon the electrical and physical specifications of the  
22          devices to be manufactured, as exemplified by the compositions  
23          disclosed in the above-mentioned prior art references. Specific  
24          examples of other conductive polymer materials compounded from  
25          other polymers and conductive fillers, as well as other fillers,  
26          anti-oxidants, and cross-linking agents, are disclosed in U.S. Patent  
27          No. 4,237,441 - van Konynenburg et al., and U.S. Patent No.  
28          5,174,924 - Yamada et al. The compounded conductive polymer  
29          formulations disclosed in these patents (as well as other



1 formulations) may be readily employed in the subject invention,  
2 with a separate gravimetric feeder for each constituent material.

3 The action of the compounding extruder 10 melts the  
4 polymer pellets and thoroughly mixes and disperses the polymer  
5 material with the carbon black to produce a homogeneous  
6 compounded conductive polymer melt (preferably about 35% to  
7 50% carbon black by volume, although a volumetric range of  
8 carbon black content of about 20% to 70% may be employed) that  
9 is discharged at relatively low pressure into the intake of a gear  
10 pump 16. The gear pump 16 is of the positive displacement type,  
11 specifically designed for polymer extrusion. A suitable gear pump  
12 16 is the "ZENITH PEP-II" pump, of appropriate capacity (e.g.,  
13 approximately 10 cc per revolution, in the preferred embodiments  
14 of the invention). The purpose of the gear pump 16 is to allow the  
15 extruder 10 to discharge the melted conductive polymer extrudate  
16 at relatively low pressure, thereby minimizing or avoiding the  
17 introduction of unnecessary shear forces and work into the  
18 material. The gear pump 16, in turn, generates a substantially  
19 constant volumetric flow of extrudate at sufficient pressure for  
20 input into a "flex-lip" sheet die 18.

21 The sheet die 18, which is also a conventional, commercially  
22 available apparatus, forms the compounded extrudate into a  
23 continuous sheet or web 20 of precisely-controlled thickness.  
24 When thus formed, the compounded polymer is still in the melt  
25 phase. In a preferred embodiment of the invention, the web 20  
26 has a width of about 200 mm, and a thickness of between about  
27 0.20 to about 1.0 mm, depending on the specifications of the  
28 component to be manufactured, with widths of up to about one  
29 meter and thicknesses of up to about 5 mm being achievable, if

1 desired. The thickness is maintained within a tolerance of between  
2 about  $\pm 1\%$  to about  $\pm 5\%$  by a closed loop feed-back control  
3 system, as will be described below.

4 After exiting from the sheet die 18, the web 20 is fed into a  
5 lamination mechanism 22, having cooled to a temperature slightly  
6 below the melting point of the compounded polymer material.  
7 The lamination mechanism comprises a first foil feed reel or payoff  
8 reel 24 and a second foil feed reel or pay-off reel 26, which  
9 respectively contain first and second continuous sheets or webs 28,  
10 30 of conductive metal foil (preferably nickel-plated copper,  
11 although solid copper, nickel, aluminum, and other metals may be  
12 used) having a thickness of about 0.025 mm, and having  
13 approximately the same width as the web 20 of compounded  
14 polymer. (The physical configuration of the foil webs 28, 30, as  
15 used in the preferred embodiments of the invention, will be more  
16 specifically described below.) As the foil webs 28, 30 are unwound  
17 from their respective pay-off reels 24, 26, they are respectively  
18 passed through first and second foil pre-heaters 32, 34. The  
19 pre-heaters 32, 34 respectively heat the foil webs 28, 30 to a  
20 temperature slightly above the melting point of the compounded  
21 polymer web 20. Preferably, the pre-heaters 32, 34 are of the hot  
22 air type; of conventional design.

23 After leaving the sheet die 18, the compounded polymer web  
24 20 is passed between a pair of lamination rollers 36, which are  
25 heated to approximately the temperature of the compounded  
26 polymer web 20. After pre-heating, the foil webs 28, 30 are  
27 likewise passed between the lamination rollers 36, such that the  
28 first foil web 28 is laminated onto the top surface of the  
29 compounded polymer web 20, and the second foil web 30 is

1 laminated onto the bottom surface of the compounded polymer  
2 web 20 by the pressure applied by the rollers 36. The result is a  
3 continuous three-layer web 38 (Figure 2), with a compounded  
4 polymer layer 40 sandwiched between an upper foil layer 41 and a  
5 lower foil layer 42. The laminated web 38 may be passed through  
6 an optional thickness gauge 44, of any of several conventional  
7 designs, producing an output signal that is indicative of the web  
8 thickness, and that may be fed into a microprocessor used in the  
9 control of the process, as described below.

10 The laminated web 38 is exposed to the atmosphere for a  
11 short period of time, allowing it to cool to below the melting point  
12 of the compounded polymer. The cooled laminated web 38 may  
13 optionally be fed into a "guillotine"-type cutter mechanism 46, of  
14 conventional design, which cuts it into sheets 48 of measured  
15 length (e.g., about 300 to about 450 mm). The cutter mechanism  
16 46 then discharges the cut sheets 48 onto a conveyor 50 for  
17 stacking, prior to the steps of forming and packaging the individual  
18 polymer PTC active elements, as will be described below.  
19 Alternatively, the continuous laminated web 38 may be re-wound  
20 into a roll (not shown), and then unwound for performing the steps  
21 of forming and packaging the individual active elements. A typical  
22 polymer PTC active element 52, manufactured in accordance with  
23 the above-described process, is shown in cross-section in Figure 4.

24 As previously mentioned, the above-described manufacturing  
25 process is controlled by a closed loop feedback control system,  
26 under the control of a microprocessor 54, as shown in Figure 5.  
27 The algorithm used by the microprocessor uses the inlet pressure  
28 of the gear pump 16 as the controlling parameter, with a  
29 predetermined inlet pressure as the set point. Thus, by means of a

1 pressure transducer 56 at the pump inlet, the pump inlet pressure  
2 is measured, and a measured pressure signal is fed to the  
3 microprocessor 54. The microprocessor 54 then periodically  
4 compares the value of the measured pressure signal with a stored  
5 nominal or set point pressure value. The comparison yields a  
6 pressure difference signal that is fed to a feeder control mechanism  
7 58 and an extruder control mechanism 60 respectively to control  
8 the feed rates of the gravimetric feeders 12, 14, and the rotation  
9 rate of the screws in the twin screw extruder 10 in such a manner  
10 as to minimize the absolute value of the pressure difference signal.  
11 (The feeder control mechanism 58 and the extruder control  
12 mechanism 60 are conventional electromechanical control  
13 mechanisms that well-known to those of ordinary skill in the  
14 pertinent arts.) The algorithm compensates for the residence time  
15 (typically about 30 to 180 seconds) of the compounded polymer  
16 within the extruder 10. Since the pump inlet pressure is a function  
17 of the feed rates and extruder screw rotation rate, the pump inlet  
18 pressure can be maintained at or very close to the set point  
19 pressure by controlling the feed rates and the extruder screw  
20 rotation rate. With these parameters thus controlled, consistency  
21 in the compounded polymer material can be maintained to within  
22 close tolerances.

23 If a thickness gauge 44 is used, as described above, another  
24 closed loop feedback system may be employed to maintain the  
25 thickness of the laminated web 38 to within close tolerances. The  
26 thickness control system employs a measured thickness signal  
27 generated by the thickness gauge 44 and fed to the microprocessor  
28 54. The microprocessor contains an algorithm that compares the  
29 value of the measured thickness signal to a stored set point or

1 nominal thickness value. This comparison yields a thickness  
2 difference signal that is fed to a sheet die control mechanism 62 to  
3 control the outlet gap of the sheet die 18. Also, the thickness  
4 difference signal may be fed to a roller control mechanism 64 to  
5 control the pressure applied by the lamination rollers 36 in  
6 laminating the foil webs 28, 30 to the compounded polymer web 20  
7 (by controlling the gap width between the rollers 36), and/or the  
8 speed at which the rollers 36 draw the material down from the  
9 sheet die 18. At least one of these operational parameters (i.e.,  
10 the sheet die outlet gap, the roller pressure, and/or the roller draw  
11 down speed) is controlled so as to minimize the absolute value of  
12 the thickness difference signal. (The sheet die control mechanism  
13 62 and the roller control mechanism 64 are conventional  
14 electromechanical control mechanisms that well-known to those of  
15 ordinary skill in the pertinent arts.) The thickness of the laminated  
16 web 38 is thus a function of (a) the outlet gap width of the sheet  
17 die 18; (b) the pressure applied by the lamination rollers 36; and  
18 (c) the draw down speed of the rollers 36. Therefore, control of  
19 one or more of these parameters yields precise control of the  
20 thickness of the laminated web 38.

21 It will be appreciated from the foregoing description that the  
22 manufacturing process used in the present invention, by avoiding  
23 or minimizing the above-described shortcomings of batch  
24 processing methods, provides substantially improved uniformity,  
25 consistency, and predictability in the electrical and physical  
26 characteristics of the conductive polymer material, and,  
27 consequently, of the electrical devices formed from such material.  
28 Furthermore, these advantages are achieved while maintaining  
29 manufacturing costs acceptably low.

1           **B.     First and Second Preferred Embodiments**  
2                   **of an SMT-Type Conductive Polymer Device**

3           Figures 6A through 13 illustrate the construction of first and  
4           second preferred embodiments of an SMT-type polymer PTC  
5           device, including a laminated conductive polymer active element  
6           made in accordance with the above-described process.

7           Figure 6A illustrates the above-mentioned metal foil webs  
8           28, 30, configured as first and second (top and bottom) lead frame  
9           blanks, respectively. Each of the foil webs or lead frame blanks 28,  
10          30 includes a row of evenly-spaced registration holes 70 along one  
11          edge. The lead frame blanks 28, 30 are oriented prior to the  
12          above-described lamination process so that after the polymeric web  
13          20 is laminated between them, the laminated web 38 so formed  
14          includes an opposed parallel pair of carrier strips 72a, 72b, each of  
15          which includes a row of registration holes 70, as shown in Figure  
16          6A.

17          As shown in Figure 6B, the laminated web 38 is then cut  
18          and trimmed (by conventional means, well-known in the art) to  
19          form a plurality of individual laminated conductive polymer active  
20          elements 74, each of which has a conductive polymer element 76  
21          laminated between a first electrode 78 formed from the first lead  
22          frame blank 28 and a second electrode 80 formed from the second  
23          lead frame blank 30. Each of the first electrodes 78 is connected  
24          to one of the carrier strips 72a by one of a first plurality of integral  
25          lead elements 82a, while each of the second electrodes 80 is  
26          attached to the other carrier strip 72b by one of a second plurality  
27          of oppositely-directed integral lead elements 82b.

28          For the purposes of the present invention, it may be  
29          advantageous to treat the lead frame blanks 28, 30, by one of

1 several methods known in the art, to provide an improved low  
2 resistivity bond with the polymeric web 20. For example, the  
3 surfaces of the lead frame blanks 28, 30 that will contact the  
4 polymeric web 20 may be "nodularized" by electrodeposition, as  
5 taught, for example, in U.S. Patents Nos. 3,220,109 and 3,293,109,  
6 the disclosures of which are incorporated herein by reference.

7       Figures 7 and 8 illustrate an individual laminated conductive  
8 polymer active element 74, shown prior to being packaged in a  
9 housing, as will be described below. As shown in Figures 7 and 8,  
10 the active element 74 is separated from the carrier strips 72a, 72b,  
11 and the packaging procedure may be performed after such  
12 separation. It is more efficient, however, to package the active  
13 elements 74 while they are still attached to the carrier strips 72a,  
14 72b, as shown in Figure 6B. As also shown in Figures 7 and 8, the  
15 lead elements 82a, 82b may advantageously be formed into a  
16 downward S-bend 84 near their respective junctures with the  
17 electrodes 78, 80. The S-bends 84, which are preferably formed  
18 while the carrier strips 72a, 72b are still attached, provide  
19 improved adhesion of the housing material, as will be described  
20 below.

21       In accordance with the present invention, there are two  
22 preferred methods of packaging the active elements 74. In the first  
23 method, the lead frame (the active elements 74 attached to the  
24 carrier strips 72a, 72b) is passed through a molding machine (not  
25 shown), of a type well-known in the art, with the registration holes  
26 70 providing proper location of the active elements 74 during the  
27 molding process. The active elements 74 are over-molded with a  
28 suitable thermoplastic to form an over-molded conformal housing  
29 86 in which the active elements 74 are hermetically encapsulated,

1 as shown in Figure 9, thereby forming a packaged conductive  
2 polymer device 88 in accordance with a first preferred embodiment  
3 of the invention. The encapsulation material of the conformal  
4 housing 86 should have a coefficient of thermal expansion that is  
5 as close to that of the polymeric layer 40 as possible. The  
6 packaged devices 88 are then cut from the carrier strips 72a, 72b,  
7 and the leads 82a, 82b are trimmed and bent into the SMT  
8 configuration shown in Figures 10 and 11.

9 Alternatively, the active elements 74 can be packaged in a  
10 pre-molded housing 90, as shown in Figures 12 and 13. In this  
11 variation, housings 90 are pre-molded with an internal cavity 91,  
12 one open side, and two opposed ends 92, each provided with a slot  
13 94. The cavities 91 are sized large enough to receive an active  
14 element 74 through the one open side. Thus, each of the active  
15 elements 74, while still attached to the carrier strips 72a, 72b, and  
16 after formation of the S-bends 84 in the lead elements 82a, 82b, is  
17 placed inside one of the pre-molded housings 90, with the lead  
18 elements 82a, 82b received in the slots 94, as shown in Figure 12.  
19 This installation process can easily be automated, with the active  
20 elements 74 properly located with respect to the housings 90 by  
21 means of the registration holes 70.

22 After the active elements 74 are installed in the housing  
23 cavities 91, cavity 91 is filled with a potting material 96, preferably  
24 an epoxy resin or silicone-rubber compound, of any suitable type  
25 well-known in the art. Preferably, the selected potting material 96  
26 has a coefficient of thermal expansion that is as close as possible to  
27 that of the polymeric layer 40 of the active element 74. The result,  
28 shown in Figure 13, is a packaged conductive polymer PTC device  
29 98, in accordance with a second preferred embodiment of the



1 invention, in which the open side of the housing 90 is hermetically  
2 sealed by the potting material 96, which also fills the cavity 91  
3 around the active element 74 and the junctures between the lead  
4 elements 82a, 82b and the electrodes 78, 80, respectively.

5 Finally, as with the previously-described embodiment, the  
6 lead elements 82a, 82b, after being cut from the carrier strips 72a,  
7 72b, are formed into the SMT configuration shown in Figures 10  
8 and 11.

9 **C. Third and Fourth Preferred Embodiments**  
10 **of an SMT-Type Conductive Polymer Device**

11 Figures 14 through 17 illustrate the construction of third and  
12 fourth preferred embodiments of an SMT-type polymer PTC  
13 device, including a laminated conductive polymer active element  
14 made in accordance with the above-described process.

15 In constructing the third and fourth embodiments, the  
16 laminated web 38 is first cut into a strip 100 of desired length.  
17 The laminated strip 100 comprises a conductive polymer layer 40  
18 sandwiched between an upper foil layer 41 and a lower foil layer  
19 42, as previously described with reference to Figure 2. First and  
20 second pluralities of discrete lead elements 102a, 102b, selected  
21 from the appropriate material (preferably nickel, copper, or  
22 beryllium-copper) and cut to the correct size, are respectively  
23 attached to first and second carrier strips 104a, 104b to form first  
24 and second lead frames 106a, 106b. The carrier strips 104a, 104b  
25 are provided with registration holes 108.

26 Next, the laminated strip 100 is attached to the first and  
27 second lead frames 106a, 106b by soldering the first plurality of  
28 lead elements 102a to the upper foil layer 41 and the second  
29 plurality of lead elements 102b to the lower foil layer 42, as shown

1 in Figure 14A. The laminated strip 100 is then cut to separate it  
2 into individual active elements 74, as shown in Figure 14B, each  
3 with a conductive polymer layer 109 sandwiched between an upper  
4 electrode 110 formed from the upper foil layer 41, and a lower  
5 electrode 112 formed from the lower foil layer 42. The upper  
6 electrode 110 is still attached to the first carrier strip 104a by one  
7 of the first plurality of lead elements 102a, and the lower electrode  
8 112 is still attached to the second carrier strip 104b by one of the  
9 second plurality of lead elements 102b.

10 Alternatively, the laminated strip 100 can be pre-cut into  
11 into a plurality of laminated chips dimensioned as individual active  
12 elements 74, each with an upper electrode 110 and and a lower  
13 electrode 112. These laminated chips are then attached to the first  
14 and second lead frames 106a, 106b by soldering one of the first  
15 plurality of lead elements 102a to each of the upper electrodes 110,  
16 and one of the second plurality of lead elements 102b to each of  
17 the lower electrodes 112. Thus, in this alternate method, the step  
18 illustrated in Figure 14A is not performed, and the cutting of the  
19 individual active elements is performed before they are soldered to  
20 the lead frame.

21 In either case, after the active elements 74 are formed and  
22 while they are still attached to the lead frames 106a, 106b, a  
23 downward S-bend 114 is formed in each of the lead elements 102a,  
24 102b near its juncture with its associated electrode 110 or 112.

25 Either of the two packaging methods described above with  
26 respect to the first and second embodiments can be used to  
27 package the active elements 74 of the third and fourth  
28 embodiments of the invention. In the first method, the lead  
29 frames 106a, 106b, with the active elements 74 attached to it, is

1       passed through a molding machine (not shown), of a type  
2       well-known in the art, with the registration holes 108 in the carrier  
3       strips 104a, 104b providing proper location of the active elements  
4       74 during the molding process. The active elements 74 are  
5       over-molded with a suitable thermoplastic to form an over-molded  
6       conformal housing 116, in which the active elements 74 are  
7       hermetically encapsulated, as shown in Figure 15, thereby forming  
8       a packaged conductive polymer device 118 in accordance with a  
9       third preferred embodiment of the invention. The encapsulation  
10      material of the conformal housing 116 should have a coefficient of  
11      thermal expansion that is as close to that of the polymeric layer 40  
12      as possible. The packaged devices 118 are then cut from the  
13      carrier strips 104a, 104b, and the leads 102a, 102b are trimmed and  
14      bent into the SMT configuration shown in Figures 10 and 11.

15             Alternatively, the active elements 74 can be packaged in a  
16      pre-molded housing 120, as shown in Figures 16 and 17. In this  
17      variation, housings 120 are pre-molded with an internal cavity 121,  
18      one open side, and two opposed ends 122, each provided with a  
19      slot 124. The cavities 121 are sized large enough to receive an  
20      active element 74 through the one open side. Thus, each of the  
21      active elements 74, while still attached to the lead frames 106a,  
22      106b, and after formation of the S-bends 114 in the lead elements  
23      102a, 102b, is placed inside one of the pre-molded housings 120,  
24      with the lead elements 102a, 102b received in the slots 124, as  
25      shown in Figure 16. This installation process can easily be  
26      automated, with the active elements 74 properly located with  
27      respect to the housings 120 by means of the registration holes 108.

28             After the active elements 74 are installed in the cavities 121,  
29      each housing 120 is filled with a potting material 126, preferably an

1 epoxy resin or silicone-rubber compound, of any suitable type  
2 well-known in the art. Preferably, the selected potting material 126  
3 has a coefficient of thermal expansion that is as close as possible to  
4 that of the polymeric layer 40 of the active element 74. The result,  
5 shown in Figure 17, is a packaged conductive polymer PTC device  
6 128, in accordance with a fourth preferred embodiment of the  
7 invention, in which the open side of the housing 120 is hermetically  
8 sealed by the potting material 126, which also fills the cavity 121  
9 around the active element 74 and the junctures between the lead  
10 elements 102a, 102b and the upper and lower electrodes 110, 112,  
11 respectively.

12 Finally, as with the previously-described embodiments, the  
13 lead elements 102a, 102b, after being cut from the carrier strips  
14 104a, 104b, are formed into the SMT configuration shown in  
15 Figures 10 and 11.

16 While several preferred embodiments of the present  
17 invention have been described herein, it will be appreciated that a  
18 number of modifications and variations, some of which have been  
19 mentioned above, will suggest themselves to those skilled in the  
20 pertinent arts. These and other modifications and variations that  
21 may suggest themselves are considered to be within the spirit and  
22 scope of the present invention, as defined in the claims that follow.

1       **WHAT IS CLAIMED IS:**

2           1.     A process for manufacturing conductive polymer  
3     electronic components, comprising the steps of:

4               (a)   controllably feeding a polymer and a conductive  
5     filler in predetermined proportions at predetermined feed rates  
6     into a compounding apparatus;

7               (b)   melting the polymer and mixing and dispersing  
8     the polymer and conductive filler in the compounding apparatus  
9     and discharging therefrom a compounded conductive polymeric  
10    extrudate in a melted state;

11              (c)   pumping the discharged extrudate into a sheet  
12    die;

13              (d)   forming the extrudate into a continuous  
14    polymeric web in the sheet die;

15              (e)   laminating the continuous polymeric web  
16    between first and second conductive foil webs to form a continuous  
17    laminated web; and

18              (f)   forming the laminated web into a plurality of  
19    conductive polymer electronic components.

20           2.     The process of Claim 1, wherein the step of pumping  
21    comprises the step of pumping the extrudate into the sheet die at a  
22    substantially constant volumetric rate.

23           3.     The process of Claim 2, further comprising the steps  
24    of:

25               (g)   measuring the pressure of the extrudate after it  
26    is discharged from the compounding apparatus and before the  
27    pumping step, and generating a measured pressure signal having a  
28    value representative of the measured pressure;

29               (h)   periodically comparing the value of the

1 measured pressure signal with a set point pressure value and  
2 generating a pressure difference signal having a value  
3 representative of the difference between the value of the measured  
4 pressure signal and the set point pressure value; and

5 (i) using the pressure difference signal to control  
6 the feed rates of the polymer and the filler and the extrusion rate  
7 of the compounding apparatus.

8 4. The process of Claim 1, further comprising the steps  
9 of:

10 measuring the thickness of the laminated web and  
11 generating a measured thickness signal having a value  
12 representative of the measured thickness of the web;

13 periodically comparing the value of the measured  
14 thickness signal with a set point thickness value and generating a  
15 thickness difference signal having a value representative of the  
16 difference between the value of the measured thickness signal and  
17 the set point thickness value; and

18 using the thickness difference signal to control the  
19 thickness of the laminated web.

20 5. The process of Claim 3, further comprising the steps  
21 of:

22 measuring the thickness of the laminated web and  
23 generating a measured thickness signal having a value  
24 representative of the measured thickness of the web;

25 periodically comparing the value of the measured  
26 thickness signal with a set point thickness value and generating a  
27 thickness difference signal having a value representative of the  
28 difference between the value of the measured thickness signal and  
29 the set point thickness value; and

1                   using the thickness difference signal to control the  
2                   thickness of the laminated web.

3               6.     The process of Claim 1, wherein the step of  
4                   laminating is performed with the polymeric web at a temperature  
5                   that is slightly below the melting point of the extrudate, and with  
6                   the first and second foil webs slightly above the melting point of  
7                   the extrudate.

8               7.     The process of Claim 3, wherein the step of  
9                   laminating is performed with the polymeric web at a temperature  
10                  that is slightly below the melting point of the extrudate, and with  
11                  the first and second foil webs slightly above the melting point of  
12                  the extrudate.

13              8.     The process of Claim 4, wherein the step of using the  
14                  thickness difference signal to control the thickness of the laminated  
15                  web comprises the step of controlling at least one of (i) the  
16                  thickness of the polymer web before the step of laminating, and  
17                  (ii) the thickness of the laminated web after the step of laminating.

18              9.     A process for manufacturing conductive polymer  
19                  electronic components, comprising the steps of:

20                   (a)   extruding a melted extrudate of conductive  
21                   polymeric material;

22                   (b)   forming the extrudate into a continuous  
23                   polymeric web;

24                   (c)   laminating the continuous polymeric web  
25                   between first and second conductive foil webs to form a continuous  
26                   laminated web; and

27                   (d)   forming the laminated web into a plurality of  
28                   conductive polymer electronic components.

29              10.    The process of Claim 9, wherein the step of extruding

1 comprises the step of discharging the extrudate at a first pressure,  
2 and wherein the step of forming comprises the steps of:

3 (b)(1) pumping the discharged extrudate into a sheet  
4 die at a second pressure that is higher than the first pressure; and

5 (b)(2) forming the continuous polymeric web in the  
6 sheet die.

7 11. The process of Claim 10, further comprising the step  
8 of maintaining the first pressure within a predetermined range.

9 12. The process of Claim 10, wherein the step of  
10 maintaining the first pressure comprises the steps of:

11 measuring the first pressure before the pumping step,  
12 and generating a measured pressure signal having a value  
13 representative of the first pressure;

14 periodically comparing the value of the measured  
15 pressure signal with a set point pressure value and generating a  
16 pressure difference signal having a value representative of the  
17 difference between the value of the measured pressure signal and  
18 the set point pressure value; and

19 using the pressure difference signal to control the step  
20 of extruding so as to tend to minimize the absolute value of the  
21 pressure difference signal, whereby the first pressure is maintained  
22 within the predetermined range.

23 13. The process of Claim 9, wherein the step of  
24 laminating is performed with the polymeric web at a temperature  
25 that is slightly below the melting point of the extrudate, and with  
26 the first and second foil webs slightly above the melting point of  
27 the extrudate.

28 14. The process of Claim 10, wherein the step of  
29 laminating is performed with the polymeric web at a temperature



1       that is slightly below the melting point of the extrudate, and with  
2       the first and second foil webs slightly above the melting point of  
3       the extrudate.

4           15.   The process of Claim 11, wherein the step of  
5       laminating is performed with the polymeric web at a temperature  
6       that is slightly below the melting point of the extrudate, and with  
7       the first and second foil webs slightly above the melting point of  
8       the extrudate.

9           16.   The process of Claim 12, wherein the step of  
10       laminating is performed with the polymeric web at a temperature  
11       that is slightly below the melting point of the extrudate, and with  
12       the first and second foil webs slightly above the melting point of  
13       the extrudate.

14          17.   The process of Claim 9, wherein the step of extruding  
15       comprises the steps of:

16               (a)(1) controllably feeding a polymer and a conductive  
17       filler into an extruding apparatus in predetermined proportions;  
18       and

19               (a)(2) melting the polymer and mixing and dispersing  
20       the polymer and conductive filler in the extruding apparatus and  
21       discharging therefrom the conductive polymeric extrudate in a  
22       melted state.

23          18.   The process of Claim 10, wherein the step of  
24       extruding comprises the steps of:

25               (a)(1) controllably feeding a polymer and a conductive  
26       filler into an extruding apparatus in predetermined proportions;  
27       and

28               (a)(2) melting the polymer and mixing and dispersing  
29       the polymer and conductive filler in the extruding apparatus and

1 discharging therefrom the conductive polymeric extrudate in a  
2 melted state.

3 19. The process of Claim 11, wherein the step of  
4 extruding comprises the steps of:

5 (a)(1) controllably feeding a polymer and a conductive  
6 filler into an extruding apparatus in predetermined proportions;  
7 and

8 (a)(2) melting the polymer and mixing and dispersing  
9 the polymer and conductive filler in the extruding apparatus and  
10 discharging therefrom the conductive polymeric extrudate in a  
11 melted state.

12 20. The process of Claim 12, wherein the step of  
13 extruding comprises the steps of:

14 (a)(1) controllably feeding a polymer and a conductive  
15 filler into an extruding apparatus in predetermined proportions;  
16 and

17 (a)(2) melting the polymer and mixing and dispersing  
18 the polymer and conductive filler in the extruding apparatus and  
19 discharging therefrom the conductive polymeric extrudate in a  
20 melted state.

21 21. The process of Claim 9, further comprising the steps  
22 of:

23 (e) measuring the thickness of the laminated web  
24 and generating a measured thickness signal having a value  
25 representative of the measured thickness of the web;

26 (f) periodically comparing the value of the  
27 measured thickness signal with a set point thickness value and  
28 generating a thickness difference signal having a value  
29 representative of the difference between the value of the measured

1 thickness signal and the set point thickness value; and

2 (g) using the thickness difference signal to control  
3 the thickness of the laminated web.

4 22. The process of Claim 10, further comprising the steps  
5 of:

6 (e) measuring the thickness of the laminated web  
7 and generating a measured thickness signal having a value  
8 representative of the measured thickness of the web;

9 (f) periodically comparing the value of the  
10 measured thickness signal with a set point thickness value and  
11 generating a thickness difference signal having a value  
12 representative of the difference between the value of the measured  
13 thickness signal and the set point thickness value; and

14 (g) using the thickness difference signal to control  
15 the thickness of the laminated web.

16 23. The process of Claim 11, further comprising the steps  
17 of:

18 (e) measuring the thickness of the laminated web  
19 and generating a measured thickness signal having a value  
20 representative of the measured thickness of the web;

21 (f) periodically comparing the value of the  
22 measured thickness signal with a set point thickness value and  
23 generating a thickness difference signal having a value  
24 representative of the difference between the value of the measured  
25 thickness signal and the set point thickness value; and

26 (g) using the thickness difference signal to control  
27 the thickness of the laminated web.

28 24. The process of Claim 12, further comprising the steps  
29 of:

- 1 (e) measuring the thickness of the laminated web  
2 and generating a measured thickness signal having a value  
3 representative of the measured thickness of the web;  
4 (f) periodically comparing the value of the  
5 measured thickness signal with a set point thickness value and  
6 generating a thickness difference signal having a value  
7 representative of the difference between the value of the measured  
8 thickness signal and the set point thickness value; and  
9 (g) using the thickness difference signal to control  
10 the thickness of the laminated web.

11 25. The process of Claim 21, wherein the step of using the  
12 thickness difference signal to control the thickness of the laminated  
13 web comprises the step of controlling at least one of (i) the  
14 thickness of the polymer web before the step of laminating, and  
15 (ii) the thickness of the laminated web after the step of laminating.

16 26. The process of Claim 22, wherein the step of using the  
17 thickness difference signal to control the thickness of the laminated  
18 web comprises the step of controlling at least one of (i) the  
19 thickness of the polymer web before the step of laminating, and  
20 (ii) the thickness of the laminated web after the step of laminating.

21 27. The process of Claim 23, wherein the step of using the  
22 thickness difference signal to control the thickness of the laminated  
23 web comprises the step of controlling at least one of (i) the  
24 thickness of the polymer web before the step of laminating, and  
25 (ii) the thickness of the laminated web after the step of laminating.

26 28. The process of Claim 24, wherein the step of using the  
27 thickness difference signal to control the thickness of the laminated  
28 web comprises the step of controlling at least one of (i) the  
29 thickness of the polymer web before the step of laminating, and

1 (ii) the thickness of the laminated web after the step of laminating.

2 29. A process for manufacturing conductive polymer  
3 electronic devices, comprising the steps of:

4 (a) continuously making a web of conductive  
5 polymer material from an extrudate comprising a mixture of a  
6 polymer and a conductive filler;

7 (b) continuously laminating the polymeric web  
8 between first and second conductive foil webs to form a laminated  
9 web; and

10 (c) forming the laminated web into a plurality of  
11 conductive polymer electronic components.

12 30. The process of Claim 29, wherein the step of  
13 continuously making a web comprises the steps of:

14 (a)(1) extruding a melted extrudate of conductive  
15 polymeric material; and

16 (a)(2) forming the extrudate into a continuous  
17 polymeric web.

18 31. The process of Claim 30, wherein the extruding step  
19 comprises the steps of:

20 (a)(1)(i) controllably feeding a polymer and a  
21 conductive filler into a compounding apparatus in predetermined  
22 proportions; and

23 (a)(1)(ii) melting the polymer and mixing and  
24 dispersing the polymer and conductive filler in the compounding  
25 apparatus and discharging therefrom the conductive polymeric  
26 extrudate in a melted state.

27 32. The process of Claim 31, further comprising the steps  
28 of:

29 (d) measuring the pressure of the extrudate after it

1 is discharged from the compounding apparatus, and generating a  
2 measured pressure signal having a value representative of the  
3 measured pressure;

4 (e) periodically comparing the value of the  
5 measured pressure signal with a set point pressure value and  
6 generating a pressure difference signal having a value  
7 representative of the difference between the value of the measured  
8 pressure signal and the set point pressure value; and

9 (f) using the pressure difference signal to control  
10 the feed rates of the polymer and the filler and the extrusion rate  
11 of the compounding apparatus.

12 33. The process of Claim 29, further comprising the steps  
13 of:

14 measuring the thickness of the laminated web and  
15 generating a measured thickness signal having a value  
16 representative of the measured thickness of the web;

17 periodically comparing the value of the measured  
18 thickness signal with a set point thickness value and generating a  
19 thickness difference signal having a value representative of the  
20 difference between the value of the measured thickness signal and  
21 the set point thickness value; and

22 using the thickness difference signal to control the  
23 thickness of the laminated web.

24 34. The process of Claim 30, further comprising the steps  
25 of:

26 measuring the thickness of the laminated web and  
27 generating a measured thickness signal having a value  
28 representative of the measured thickness of the web;

29 periodically comparing the value of the measured

1 thickness signal with a set point thickness value and generating a  
2 thickness difference signal having a value representative of the  
3 difference between the value of the measured thickness signal and  
4 the set point thickness value; and

5 using the thickness difference signal to control the  
6 thickness of the laminated web.

7 35. The process of Claim 31, further comprising the steps  
8 of:

9 measuring the thickness of the laminated web and  
10 generating a measured thickness signal having a value  
11 representative of the measured thickness of the web;

12 periodically comparing the value of the measured  
13 thickness signal with a set point thickness value and generating a  
14 thickness difference signal having a value representative of the  
15 difference between the value of the measured thickness signal and  
16 the set point thickness value; and

17 using the thickness difference signal to control the  
18 thickness of the laminated web.

19 36. The process of Claim 22, further comprising the steps  
20 of:

21 measuring the thickness of the laminated web and  
22 generating a measured thickness signal having a value  
23 representative of the measured thickness of the web;

24 periodically comparing the value of the measured  
25 thickness signal with a set point thickness value and generating a  
26 thickness difference signal having a value representative of the  
27 difference between the value of the measured thickness signal and  
28 the set point thickness value; and

29 using the thickness difference signal to control the

1 thickness of the laminated web.

2 37. The process of Claim 29, wherein the step of  
3 laminating is performed with the polymeric web at a temperature  
4 that is slightly below the melting point of the extrudate, and with  
5 the first and second foil webs slightly above the melting point of  
6 the extrudate.

7 38. The process of Claim 30, wherein the step of  
8 laminating is performed with the polymeric web at a temperature  
9 that is slightly below the melting point of the extrudate, and with  
10 the first and second foil webs slightly above the melting point of  
11 the extrudate.

12 39. The process of Claim 31, wherein the step of  
13 laminating is performed with the polymeric web at a temperature  
14 that is slightly below the melting point of the extrudate, and with  
15 the first and second foil webs slightly above the melting point of  
16 the extrudate.

17 40. The process of Claim 32, wherein the step of  
18 laminating is performed with the polymeric web at a temperature  
19 that is slightly below the melting point of the extrudate, and with  
20 the first and second foil webs slightly above the melting point of  
21 the extrudate.

22 41. The process of Claim 33, wherein the step of using the  
23 thickness difference signal to control the thickness of the laminated  
24 web comprises the step of controlling at least one of (i) the  
25 thickness of the polymer web before the step of laminating, and  
26 (ii) the thickness of the laminated web after the step of laminating.

27 42. The process of Claim 34, wherein the step of using the  
28 thickness difference signal to control the thickness of the laminated  
29 web comprises the step of controlling at least one of (i) the



1 thickness of the polymer web before the step of laminating, and  
2 (ii) the thickness of the laminated web after the step of laminating.

3 43. The process of Claim 35, wherein the step of using the  
4 thickness difference signal to control the thickness of the laminated  
5 web comprises the step of controlling at least one of (i) the  
6 thickness of the polymer web before the step of laminating, and  
7 (ii) the thickness of the laminated web after the step of laminating.

8 44. The process of Claim 36, wherein the step of using the  
9 thickness difference signal to control the thickness of the laminated  
10 web comprises the step of controlling at least one of (i) the  
11 thickness of the polymer web before the step of laminating, and  
12 (ii) the thickness of the laminated web after the step of laminating.

13 45. Apparatus for manufacturing an article of  
14 manufacture comprising a conductive polymer layer laminated  
15 between first and second metallic layers, the apparatus comprising:

16 a compounding extruder mechanism for making a  
17 conductive polymer extrudate in the melt phase from a polymer  
18 material and a conductive filler material;

19 a feed mechanism for separately and controllably  
20 feeding the polymer material and the conductive filler material to  
21 the compounding extruder mechanism in predetermined  
22 proportions;

23 a die mechanism forming the extrudate into a  
24 continuous conductive polymer web having top and bottom  
25 surfaces;

26 a laminating mechanism for laminating a first  
27 continuous metallic foil web onto the top surface of the polymer  
28 web and a second continuous metallic foil web onto the bottom  
29 surface of the polymer web, thereby forming a continuous

1 laminated web

2 having a polymer layer laminated between first and second  
3 metallic layers.

4 46. The apparatus of Claim 45, wherein the compounding  
5 extruder mechanism discharges the extrudate at a first pressure,  
6 and wherein the apparatus further comprises:

7 a pump fluidly connected between the compounding  
8 extruder mechanism and the die mechanism for feeding the  
9 extrudate to the die mechanism at a second pressure that is higher  
10 than the first pressure.

11 47. The apparatus of Claim 45, wherein the compounding  
12 extruder mechanism comprises a twin screw compounding extruder.

13 48. The apparatus of Claim 45, wherein the compounding  
14 extruder mechanism discharges the extrudate at a first pressure,  
15 the apparatus further comprising:

16 a pressure control system, responsive to the first  
17 pressure, that maintains the first pressure substantially equal to a  
18 predetermined set point pressure value.

19 49. The apparatus of Claim 48, wherein the feed  
20 mechanism is operable to feed the polymer material and the filler  
21 material at controllable feed rates and the compounding extruder  
22 mechanism is operable to discharge the extrudate at a controllable  
23 extrusion rate, the first pressure being at least partly determined by  
24 the extrusion rate, and wherein the pressure control system  
25 comprises:

26 a pressure transducer disposed so as to measure the  
27 first pressure and to generate a measured pressure signal having a  
28 value indicative of the first pressure;

29 a microprocessor that is responsive to the measured

1 pressure signal by periodically comparing the value thereof with  
2 the set point pressure value, and that generates a pressure  
3 difference signal having a value that is proportional to the  
4 difference between the value of the measured pressure signal and  
5 the set point pressure value; and  
6 a pressure control mechanism, operable on the feed  
7 mechanism and the compounding extruder mechanism, that  
8 responds to the pressure difference signal by controlling the feed  
9 rates and the extrusion rate so as to minimize the absolute value of  
10 the pressure difference signal.

11 50. The apparatus of Claim 45, further comprising:  
12 a thickness control system, responsive to the thickness of the  
13 laminated web, for maintaining the thickness of the laminated web  
14 substantially at a predetermined set point thickness.

15 51. The apparatus of Claim 48, further comprising:  
16 a thickness control system, responsive to the thickness of the  
17 laminated web, for maintaining the thickness of the laminated web  
18 substantially at a predetermined set point thickness.

19 52. The apparatus of Claim 49, further comprising:  
20 a thickness control system, responsive to the thickness of the  
21 laminated web, for maintaining the thickness of the laminated web  
22 substantially at a predetermined set point thickness.

23 53. The apparatus of Claim 50, wherein the die  
24 mechanism is controllable to vary the thickness of the polymer  
25 web, and wherein the thickness control system comprises:  
26 a thickness gauge disposed so as to measure the  
27 thickness of the laminated web and to generate a measured  
28 thickness signal having a value indicative of the measured thickness  
29 thereof;

1                   a microprocessor that is responsive to the measured  
2   thickness signal by periodically comparing the value thereof with  
3   the set point thickness value, and that generates a thickness  
4   difference signal having a value that is proportional to the  
5   difference between the value of the measured thickness signal and  
6   the set point thickness value; and

7                   a thickness control mechanism, operable on the die  
8   mechanism, that responds to the thickness difference signal by  
9   controlling the die mechanism so as to minimize the absolute value  
10   of the thickness difference signal.

11           54.   The apparatus of Claim 51, wherein the die  
12   mechanism is controllable to vary the thickness of the polymer  
13   web, and wherein the thickness control system comprises:

14                   a thickness gauge disposed so as to measure the  
15   thickness of the laminated web and to generate a measured  
16   thickness signal having a value indicative of the measured thickness  
17   thereof;

18                   a microprocessor that is responsive to the measured  
19   thickness signal by periodically comparing the value thereof with  
20   the set point thickness value, and that generates a thickness  
21   difference signal having a value that is proportional to the  
22   difference between the value of the measured thickness signal and  
23   the set point thickness value; and

24                   a thickness control mechanism, operable on the die  
25   mechanism, that responds to the thickness difference signal by  
26   controlling the die mechanism so as to minimize the absolute value  
27   of the thickness difference signal.

28           55.   The apparatus of Claim 52, wherein the die  
29   mechanism is controllable to vary the thickness of the polymer

1 web, and wherein the thickness control system comprises:

2 a thickness gauge disposed so as to measure the  
3 thickness of the laminated web and to generate a measured  
4 thickness signal having a value indicative of the measured thickness  
5 thereof;

6 a microprocessor that is responsive to the measured  
7 thickness signal by periodically comparing the value thereof with  
8 the set point thickness value, and that generates a thickness  
9 difference signal having a value that is proportional to the  
10 difference between the value of the measured thickness signal and  
11 the set point thickness value; and

12 a thickness control mechanism, operable on the die  
13 mechanism, that responds to the thickness difference signal by  
14 controlling the die mechanism so as to minimize the absolute value  
15 of the thickness difference signal.

16 56. The apparatus of Claim 50, wherein the laminating  
17 mechanism is controllable to vary the thickness of the laminated  
18 web, and wherein the thickness control system comprises:

19 a thickness gauge disposed so as to measure the  
20 thickness of the laminated web and to generate a measured  
21 thickness signal having a value indicative of the measured thickness  
22 thereof;

23 a microprocessor that is responsive to the measured  
24 thickness signal by periodically comparing the value thereof with  
25 the set point thickness value, and that generates a thickness  
26 difference signal having a value that is proportional to the  
27 difference between the value of the measured thickness signal and  
28 the set point thickness value; and

29 a thickness control mechanism, operable on the

1        laminating mechanism, that responds to the thickness difference  
2        signal by controlling the laminating mechanism so as to minimize  
3        the absolute value of the thickness difference signal.

4            57.    The apparatus of Claim 51, wherein the laminating  
5        mechanism is controllable to vary the thickness of the laminated  
6        web, and wherein the thickness control system comprises:

7                    a thickness gauge disposed so as to measure the  
8        thickness of the laminated web and to generate a measured  
9        thickness signal having a value indicative of the measured thickness  
10       thereof;

11                   a microprocessor that is responsive to the measured  
12       thickness signal by periodically comparing the value thereof with  
13       the set point thickness value, and that generates a thickness  
14       difference signal having a value that is proportional to the  
15       difference between the value of the measured thickness signal and  
16       the set point thickness value; and

17                   a thickness control mechanism, operable on the  
18       laminating mechanism, that responds to the thickness difference  
19       signal by controlling the laminating mechanism so as to minimize  
20       the absolute value of the thickness difference signal.

21            58.    The apparatus of Claim 52, wherein the laminating  
22       mechanism is controllable to vary the thickness of the laminated  
23       web, and wherein the thickness control system comprises:

24                   a thickness gauge disposed so as to measure the  
25       thickness of the laminated web and to generate a measured  
26       thickness signal having a value indicative of the measured thickness  
27       thereof;

28                   a microprocessor that is responsive to the measured  
29       thickness signal by periodically comparing the value thereof with

1 the set point thickness value, and that generates a thickness  
2 difference signal having a value that is proportional to the  
3 difference between the value of the measured thickness signal and  
4 the set point thickness value; and

5 a thickness control mechanism, operable on the  
6 laminating mechanism, that responds to the thickness difference  
7 signal by controlling the laminating mechanism so as to minimize  
8 the absolute value of the thickness difference signal.

9 59. An electronic device, comprising:

10 an active element, comprising a layer of conductive  
11 polymeric material sandwiched between first and second conductive  
12 electrode layers;

13 a first terminal lead having a first juncture with the  
14 first electrode layer;

15 a second terminal lead having a second juncture with  
16 the second terminal layer; and

17 an insulative package enclosing the active element and  
18 the first and second junctures.

19 60. The electronic device of Claim 59, wherein the  
20 package is a conformal housing over-molded around and  
21 hermetically sealing the active element and the first and second  
22 junctures.

23 61. The electronic device of Claim 59, wherein the  
24 package comprises:

25 a pre-molded housing having a cavity in which the  
26 active element is seated; and

27 a sealing element filling the cavity around the active  
28 element and the first and second junctures;

29 62. The electronic device of Claim 61, wherein the

1 housing includes first and second end walls, each of the end walls  
2 having a slot through which the first and second terminal leads  
3 respectively extend.

4 63. The electronic device of Claim 59, wherein the first  
5 terminal lead is formed integrally with the first electrode layer and  
6 the second terminal lead is formed integrally with the second  
7 electrode layer.

8 64. The electronic device of Claim 60, wherein the first  
9 terminal lead is formed integrally with the first electrode layer and  
10 the second terminal lead is formed integrally with the second  
11 electrode layer.

12 65. The electronic device of Claim 61, wherein the first  
13 terminal lead is formed integrally with the first electrode layer and  
14 the second terminal lead is formed integrally with the second  
15 electrode layer.

16 66. The electronic device of Claim 62, wherein the first  
17 terminal lead is formed integrally with the first electrode layer and  
18 the second terminal lead is formed integrally with the second  
19 electrode layer.

20 67. A method of making an electronic device, comprising  
21 the steps of:

22 providing a first length of conductive metal foil having  
23 a peripheral edge formed as a first carrier strip;

24 providing a second length of conductive metal foil  
25 having a peripheral edge formed as a second carrier strip;

26 laminating a layer of conductive polymeric material  
27 between the first and second lengths of conductive metal foil to  
28 form a laminated strip having the first and second carrier strips  
29 along opposed edges;



1                   forming the laminated strip into a plurality of active  
2           elements, each comprising a layer of conductive polymer material  
3           sandwiched between a first planar metal foil electrode connected  
4           to the first carrier strip by a first terminal lead element and a  
5           second planar metal foil electrode connected to the second carrier  
6           strip by a second terminal lead element;

7                   enclosing each of the active elements in an insulative  
8           package; and

9                   separating the first and second terminal lead elements  
10          from the first and second carrier strips, respectively.

11           68.    The method of Claim 67, wherein the enclosing step  
12          comprises the step of overmolding a conformal housing around  
13          each of the active elements.

14           69.    The method of Claim 67, wherein the enclosing step  
15          comprises the steps of:

16                   for each of the active elements, providing a  
17          pre-molded housing having a cavity;

18                   inserting an active element into the cavity of each of  
19          the pre-molded housings; and

20                   hermetically sealing each cavity with sealing material  
21          placed in the cavity around the active element.

22           70.    A method of making an electronic device, comprising  
23          the steps of:

24                   providing a laminated strip comprising a conductive  
25          polymer layer sandwiched between first and second metal layers;

26                   providing a first lead frame comprising a first plurality  
27          of lead members connected to a first carrier strip;

28                   providing a second lead frame comprising a second  
29          plurality of lead members connected to a second carrier strip;

1                   attaching the first plurality of lead members to the  
2       first metal layer;  
3                   attaching the second plurality of lead members to the  
4       second metal layer;  
5                   forming the laminated strip into a plurality of active  
6       elements, each comprising a conductive polymer layer sandwiched  
7       between a first electrode formed from the first metal layer and a  
8       second electrode formed from the second metal layer, the first  
9       electrode being attached to the first carrier strip by one of the first  
10      plurality of lead elements and the second electrode being attached  
11      to the second carrier strip by one of the second plurality of lead  
12      elements;  
13                  enclosing each of the active elements in an insulative  
14      package; and  
15                  separating the first and second lead elements from the  
16      first and second carrier strips, respectively.

17           71.    The method of Claim 70, wherein the enclosing step  
18      comprises the step of overmolding a conformal housing around  
19      each of the active elements.

20           72.    The method of Claim 70, wherein the enclosing step  
21      comprises the steps of:

22                  for each of the active elements, providing a  
23      pre-molded housing having a cavity;

24                  inserting an active element into the cavity of each of  
25      the pre-molded housings; and

26                  hermetically sealing each cavity with sealing material  
27      placed in the cavity around the active element.

28           73.    The method of Claim 70, wherein the attaching steps  
29      are performed by soldering.

1           74. The method of Claim 71, wherein the attaching steps  
2           are performed by soldering.

3           75. The method of Claim 72, wherein the attaching steps  
4           are performed by soldering.

5           76. A method of making an electronic device, comprising  
6           the steps of:

7                 providing a laminated strip comprising a conductive  
8                 polymer layer sandwiched between first and second metal layers;

9                 forming the laminated strip into a plurality of active  
10                elements, each comprising a conductive polymer layer sandwiched  
11                between a first electrode formed from the first metal layer and a  
12                second electrode formed from the second metal layer, the first  
13                electrode being attached to the first carrier strip by one of the first  
14                plurality of lead elements and the second electrode being attached  
15                to the second carrier strip by one of the second plurality of lead  
16                elements;

17                providing a first lead frame comprising a first plurality  
18                of lead members connected to a first carrier strip;

19                providing a second lead frame comprising a second  
20                plurality of lead members connected to a second carrier strip;

21                attaching each of the first plurality of lead members to  
22                the first electrode of one of the active elements;

23                attaching each of the second plurality of lead  
24                members to the second electrode of one of the active elements;

25                enclosing each of the active elements in an insulative  
26                package; and

27                separating the first and second lead elements from the  
28                first and second carrier strips, respectively.

29           77. The method of Claim 76, wherein the enclosing step

1 comprises the step of overmolding a conformal housing around  
2 each of the active elements.

3 78. The method of Claim 76, wherein the enclosing step  
4 comprises the steps of:

5 for each of the active elements, providing a premolded  
6 housing having a cavity;

7 inserting an active element into the cavity of each of  
8 the pre-molded housings; and

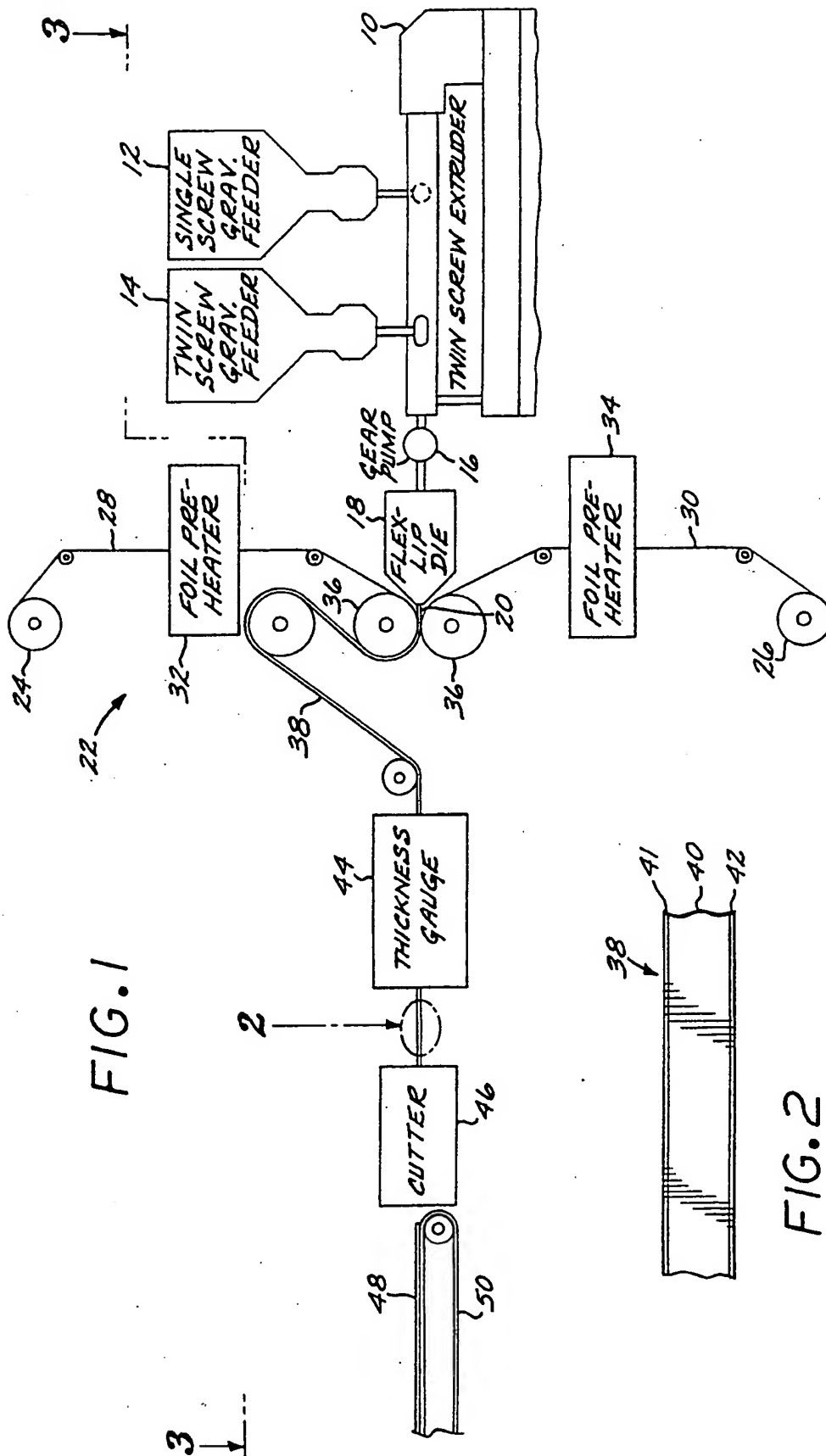
9 hermetically sealing each cavity with sealing material  
10 placed in the cavity around the active element.

11 79. The method of Claim 76, wherein the attaching steps  
12 are performed by soldering.

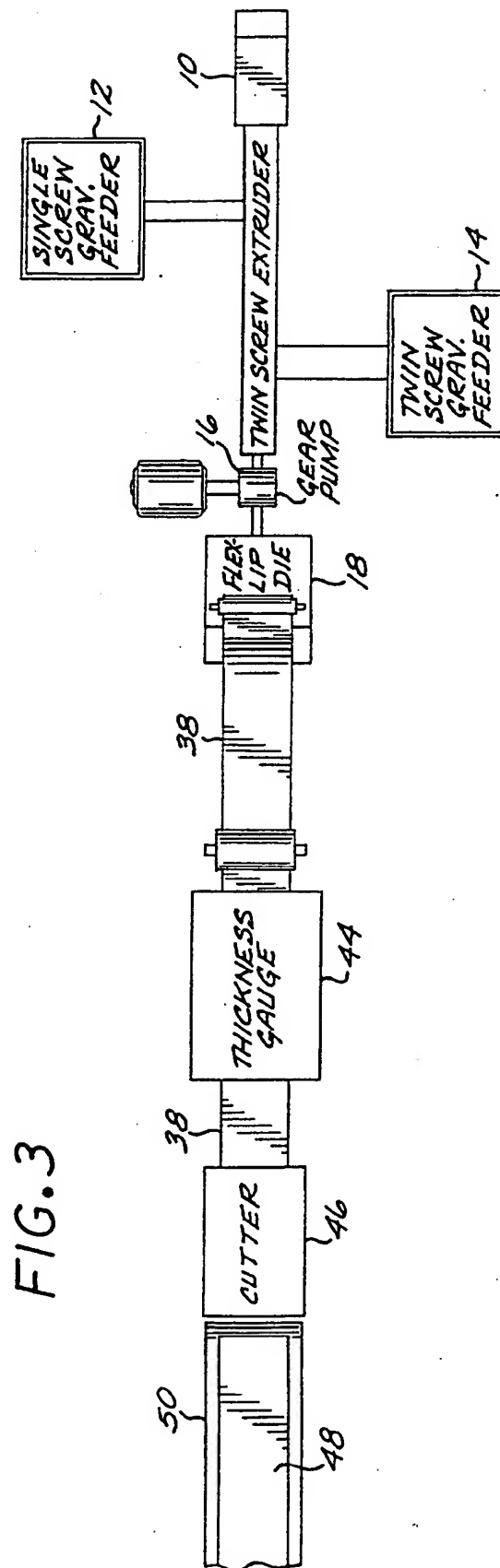
13 80. The method of Claim 77, wherein the attaching steps  
14 are performed by soldering.

15 81. The method of Claim 78, wherein the attaching steps  
16 are performed by soldering.

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2/5



3/5

FIG. 4

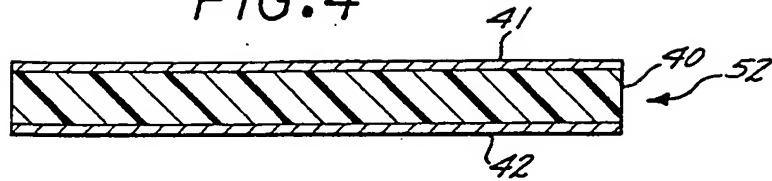


FIG. 5

